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STATUS OF THE STONY BROOK SUPERCONDUCTING HEAVY-ION LINAC*

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Summary

We describe the present status of the State University of New York at Stony Brook Superconducting Heavy-Ion LINAC (SUNYLAC). The LINAC will extend at very modest cost the capabilities of the existing FN tandem Van de Graaff into the energy range 5-10 MeV/A for light heavy-ions from oxygen to bromine. The active elements are 43 lead-plated copper superconducting resonators of the split-loop type optimized for either velocity $\beta=v/c=0.055$ or $\beta=0.10$. Phase and amplitude of each resonator is independently set through RF-feedback controllers interfaced to an overall computer control system.

Full scale construction work began in July, 1979 following the in-beam demonstration of a prototype LINAC module containing 4 low-β resonators, and the majority of the installation work on the beam transport and refrigeration systems was completed in the summer of 1980. The project is now well into its final assembly and testing phase, with the completion of assembly scheduled in early 1982. We describe details of the design of key elements of the LINAC and the initial operating experience with the injection beam path, helium refrigerator and first production accelerator module. The progress of a continuing program aimed at optimizing crucial aspects of the LINAC is also reviewed.

I. Introduction

A superconducting LINAC is under construction at Stony Brook to extend the useful mass range of the existing FN tandem accelerator to $A\simeq100$. The equivalent dc energy gain of the LINAC will be $\sim$19 MV/charge at an accelerating gradient of 2.5 MV/m, giving an overall output energy comparable to that achievable with a 20-25 MV tandem. Operation at this accelerating gradient has been demonstrated to be well within the capabilities of the installed helium refrigeration system and existing phase stabilization electronics. The tandem beam will be bunched at the 9.4 MHz 16th subharmonic of the 150.4 MHz LINAC frequency to provide a convenient pulse spacing for heavy-ion time-of-flight measurements.

The LINAC is based on the lead-plated copper split loop structure developed and refined at Cal-Tech over the last decade. Two previous contributions[1,2] to accelerator conferences have presented the conceptual design of the LINAC and reported on the performance of the prototype modular unit; these papers also contain further references to earlier development work. Test results on the prototype high-β resonator were presented at the 1980 Applied Superconductivity Conference[3], and the present proceedings contains a separate contribution on the LINAC computer control system.[4] Finally, a description of the upgrading of the FN tandem for improved heavy-ion operation will be presented at the upcoming Electrostatic Accelerator Conference.[5]

II. LINAC Performance

Table 1 summarizes the main characteristics of the LINAC. Careful optimization of drift spaces has permitted a significant improvement in the packing fraction

Table 1: LINAC Characteristics

Operating frequency:	150.4 MHz
Resonator Type:	Split-loop made from Pb-plated copper
Low-β resonators:	$\beta_o=0.055$, inside length 14.0 cm, can diameter 35.5 cm
High-β resonators:	$\beta_c=0.100$, inside length 22.2 cm, can diameter 38 cm
No. of resonators:	16 low-β, grouped in modules of 4
	24 high-β, grouped in modules of 3
Resonator cooling:	Pool boiling helium at 4.5 K
Typical Losses*:	5 W at 2.5 MV/m, 8 W at 3.0 MV/m
Energy gain per resonator:	At 2.5 MV/m: 350 keV/charge (low-β)
	555 keV/charge (high-β)
Transverse focussing:	Room temperature magnetic quadrupoles, 4 kG/cm
Cryostat length:	95 cm
LINAC length:	1684 cm for 12 modules
Maximum energy gain:	19 MeV/charge at 2.5 MV/m
He consumption at 2.5 MV/m:	$\sim$250 Watts
Total installed refrigeration:	400 W at 4.5 K, with 1000 ℓ in storage
Phase Control:	Direct RF feedback, phase error $\pm0.1°$
Total RF power:	$\sim$8 KW
Total electrical usage:	$\sim$400 kW

*Applies to both low-β and high-β resonators

and consequently an increase from 11 units to 12 units in the number of modules which could be accommodated in the LINAC area. Similarly, the final production-model high-β resonator is increased in length by 1.2 cm compared to the prototype to provide the maximum amount of useful acceleration length within the constraint that all cryostats have the same external dimensions. The accelerating gradient referred to in Table I is defined as the actual energy gain of a synchronous particle ($\beta=0.055$ or 0.10) divided by the active resonator length (14.0 or 22.2 cm, respectively). These lengths do not scale exactly as β in the two types of resonators since they have two different types of end wall design.[2,3]

In an earlier status report[2] the estimated total refrigeration and RF power requirements of the LINAC were based partly on predictions of the losses and mechanical noise to be expected in the high-β resonator from the known performance of the low-β resonator. As the actual test results[3] on the prototype high-β resonator have exceeded these expectations, the overall refrigeration and RF power requirements are reduced even with the increase in output energy achieved by adding a twelfth module. Further improvements in the losses of the high-β resonator are expected from the fact that in the production model resonator the demountable joint between the split-loop assembly and the can has been eliminated by directly electron-beam welding the two parts together. The required changes in the lead-plating techniques have already been successfully tested.

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A final very significant improvement is the elimination of all flowing LN_2 circuits in the cryostats by a redesign of the RF coupler. This not only greatly simplifies the assembly of the cryostats it also is expected to save 10 liters/hour or more on the total LN_2 consumption. This savings represents a factor of two or more drop in the LN_2 consumption provided the helium refrigerator can be operated without LN_2 precool. In the refrigeration range from 200 to 400 Watts, the dominant LN_2 demand is still the 50 liters/hour required for helium precool.

III. Resonators

All 17 low-β resonators required for the LINAC have now been fabricated in the Cal-Tech shops and shipped to Stony Brook for lead plating and final assembly. These resonators are identical to the prototype resonators[2] except for minor adjustments to the end walls to bring all units to the final frequency. Also, the demountable joint between the loop assembly and the can is now made with pure Indium (a normal conductor at 4.5 K) rather than In-Sn alloy (a type II superconductor at 4.5 K). This change has certainly had no detrimental effect on the resonator performance. Depending on results on results of tests of the first production-model high-β resonator (in which the demountable joint has been entirely eliminated) the low-β resonators could possibly be retrofitted to incorporate a welded loop. Figure 1 shows the results of tests at Stony Brook on some of the low-β resonators. Results are sufficiently consistent that routine testing of individual resonators has been discontinued. The loss performance after helium conditioning reflected in Fig. 1 is actually somewhat better than the nominal design value of 5 Watts at 2.5 MV/m (Table 1).

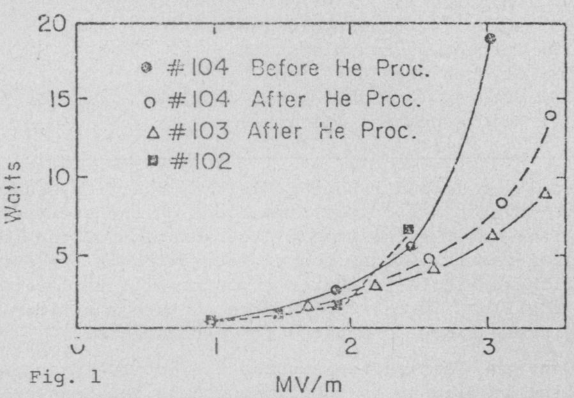

Fig. 1

A significant change in design has occured in respect to the coupling resonators. These served as variable RF transformers mounted to the superconducting resonator and were cooled by flowing LN_2. The low-frequency vibration resulting from slug flow of the LN_2 was a very significant part of the total mechanical instability of ∿100 Hz peak-to-peak. The coupling resonators have now been replaced by a simple (non-resonant) magnetic coupling loop which is driven in and out of the resonator by a rack and pinion mechanism which makes use of the same 77 K stepping motors previously employed to vary the frequency of the coupling resonator. Cooling is by simple conduction through a copper strap to the LN_2 vessel. Total range of the new coupler is $Q_{ext} \cong 10^4$ to 10^8. At the weak end there is an improvement over the coupling resonators which facilitates electrical measurements of resonator performance (Q_o).

Production of components for 27 fully-welded high-β resonators is now proceeding at Cal-Tech in parallel with tests of the new lead-plating system and other preparations for a cold test of the first production unit. Test results[3] on the prototype high-β resonator (without welded loop) demonstrate very favorable loss performance and very small mechanical frequency variations of only ∿20 Hz peak-to-peak. This result implies that no additional RF power is required to stabilize the high-β resonator even though its energy content per unit accelerating gradient is ∿2.5 times larger than that of the low-β resonator. The delivery of all high-β resonators required for the LINAC is expected to be accomplished before the end of 1981.

IV. Cryostats

Figure 2 shows an end view of the final production model modular cryostat. The vacuum vessel is fabricated from stainless steel. There were two earlier prototype stages leading up to this unit, the original cylindrical laboratory prototype[2] and a subsequent industrial prototype of the "bathtub" type. The final design emphasizes cost-effectiveness and ease of assembly by replacing the previous multiple-wire suspension system with a G-11 space frame which is hung from the LN_2 container and supports in turn the helium temperature components. This entire assembly is suspended from the top plate by stainless steel hangers which can be adjusted under vacuum. Cryogen capacities are 32 liters for LN_2 and 39 liters for liquid helium, and connections are made through bayonnets which mate to the cryogen transfer system (Fig. 3). Conservatively designed relief ports have been provided for venting in the event of a vacuum accident. Loss performance of the cryostat without resonators is under 20 W for LN_2 and ∿0.5 W for LHe. The production-model cryostats are being fabricated by the Intermagnetics General Corporation (IGC) in assembly-line fashion; 6 units have been delivered so far and the projected rate for the rest is at least one per month.

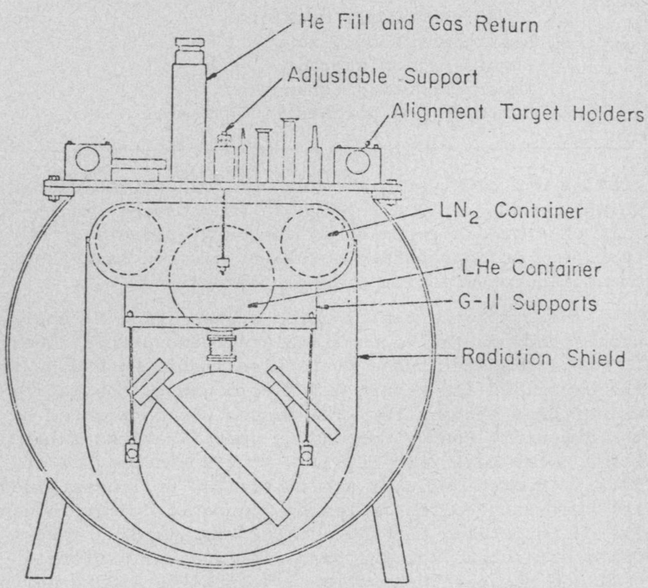

Fig. 2

V. Refrigeration

Helium refrigeration for the LINAC is provided by a TURBOCOOL 100 system rated at 400 Watts (200 Watts) with (without) 50 liters/hour of liquid nitrogen precooling. In the 200 W mode two BOC turbines are used as the expanders, while with precool only the single larger turbine is required. The system employs a single 900 SCFM Sullair screw compressor operating at 150 psig output pressure and ∿1 psig inlet pressure. The gas buffer storage is more than sufficient to accomodate all of the liquid containable in the 1000 liter liquid store. The refrigerator passed all acceptance tests in October, 1980, with a demonstrated capacity in excess of 420 Watts with LN_2 precool. Subsequent operation has been

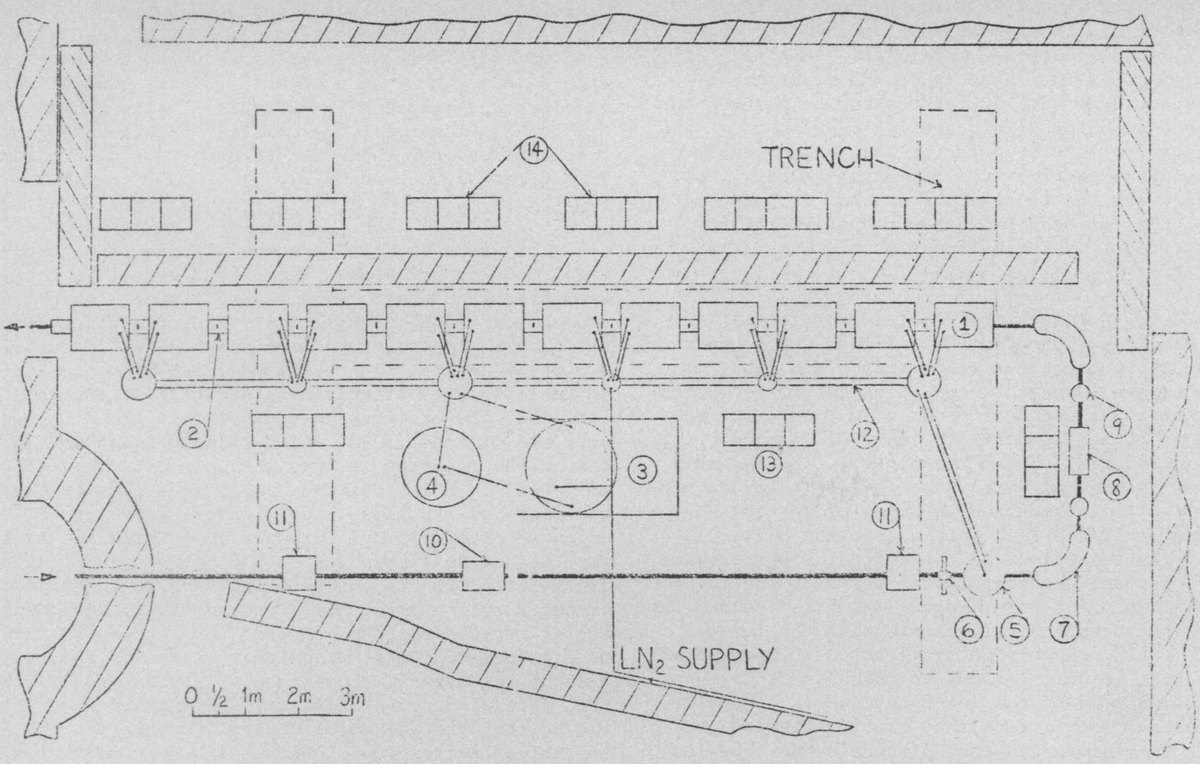

Figure 3. Layout of the Stony Brook LINAC area.

KEY:
1) Modular cryostats (4 low-β, 8 high-β).
2) LINAC quadrupole doublets.
3) Refrigerator cold box.
4) Liquid helium storage.
5) Superconducting rebuncher.
6) Stripper and diagnostic devices.
7) Dipole bending magnet.
8) Quadrupole triplet lens.
9) Ion pump.
10) Beam-line quadrupole lens.
11) Turbopump vacuum station.
12) Cryogen transfer line.
13) Quadrupole magnet power supplies.
14) Module control stations.

routine and highly reliable except for one incident in which the smaller 90H turbine failed possibly as the result of a sudden increase in the back-pressure on the turbine. An appropriate regulator has now been installed to eliminate excessive pressure excursions.

The cryogenic distribution system (Fig. 3) employs single and coaxial vacuum-insulated demountable inverted "U" type transfer tubes to furnish liquid He and N_2 to the cryostats and return 4.5 K cold gas to the refrigerator heat exchangers. The system was fabricated by the Cryogenic Energy Company to specifications calling for a total heat load of <30 W at 4.5 K and <75 W at 77 K. Cryogenic fluids are controlled by long-stemmed low heat-loss valves driven by pneumatic operators capable of throttling the flow. After repair of a leak in one of the stations, the transfer line has performed well and has been demonstrated to provide liquid helium flow rates in excess of requirements. Operation of the transfer system is by computer control[4] using level sensors developed at Stony Brook. Liquid nitrogen for the cryostats and refrigerator is brought into the area through custom-fabricated vacuum-insulated pipes (Cryolab, Inc.) connecting to a 35,000 liter LN_2 storage tank outside the laboratory.

VI. Operating Experience.

Figure 3 summarizes the layout of the LINAC area. Constraints imposed by the room and details of the beam optics have been discussed in an earlier paper.[1] Note in particular the location of the post-tandem stripper foil and superconducting rebuncher just before the isochronous 180° turn, which provides a final charge state selection prior to the LINAC. The completed LINAC will incorporate a second rebuncher in the injection beam line to develop a 100 psec time focus on the stripper; this minimizes the inevitable deterioration of the longitudinal phase space by energy straggling in the stripper. A third single-resonator cryostat will be located after the LINAC in the target area to turn the time-energy phase space as desired for experiments.

Over the last several months the entire injection beam line leading up to the first module has been extensively tested with beam, as has the rebuncher and module. In the most recent test the entire system, including the refrigerator and tandem injector, operated essentially unattended and with no adjustments at an accelerating gradient of 2.5 MV/m for a number of hours. The module was further able to operate at an average gradient of 3.0 MV/m (1.7 MeV/charge energy gain) while remaining in phase lock 99% of the time.

Additional modules are scheduled to be placed on line at a rate of about one per month, with the completion of assembly and final testing expected early 1982.

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